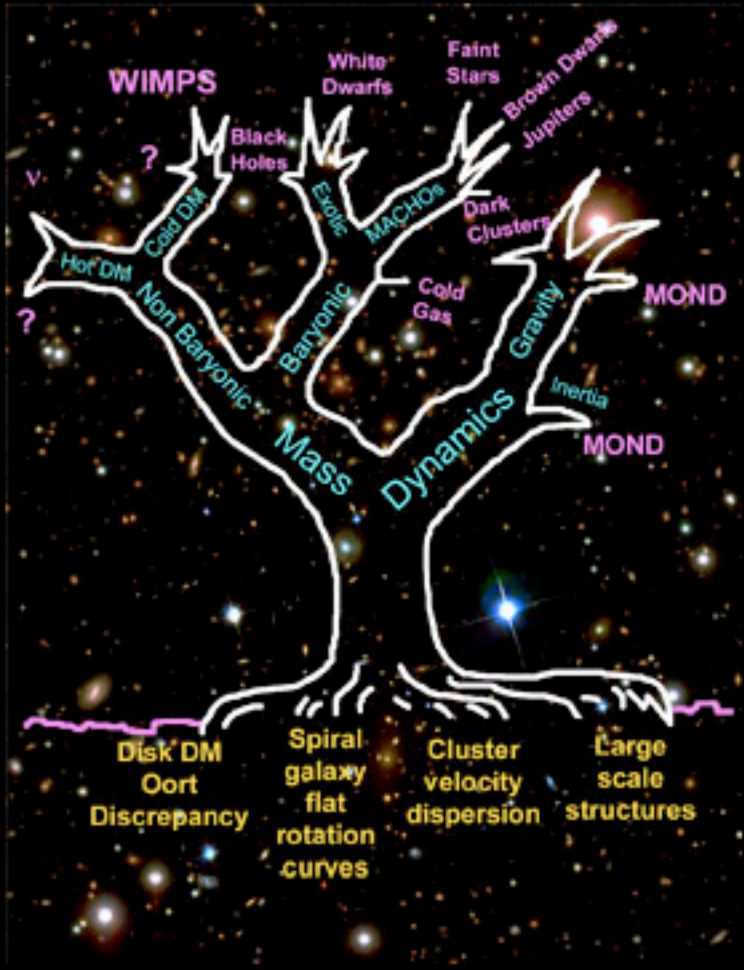
ASTR 333/433 - Dark Matter



<u>Relevant texts</u>

Galactic Dynamics
Binney & Tremaine
B&T errata

Galactic Astronomy
Binney & Merrifield
B&M errata

Galactic Astronomy
Mihalas & Binney

Galaxies in the Universe
Sparke & Gallagher

Galaxy Formation & Evolution
Mo, van den Bosch & White

Particle Dark Matter
G. Bertone *et al.*

Modern Cosmological Observations and Problems
G. Bothun

The Dark Matter Problem
R.H. Sanders

(on reserve)

Lecture slides & notes on course web page

Pruning the tree

Cold Dark Matter (CDM)

Some new particle, usually assumed to be
WIMPs (Weakly Interacting Massive Particle)
don’t interact electromagnetically,
so dark by definition.

Two big motivations:

1) total mass outweighs normal mass from BBN

2) needed to grow cosmic structure

(1) There’s more dark mass than baryons.

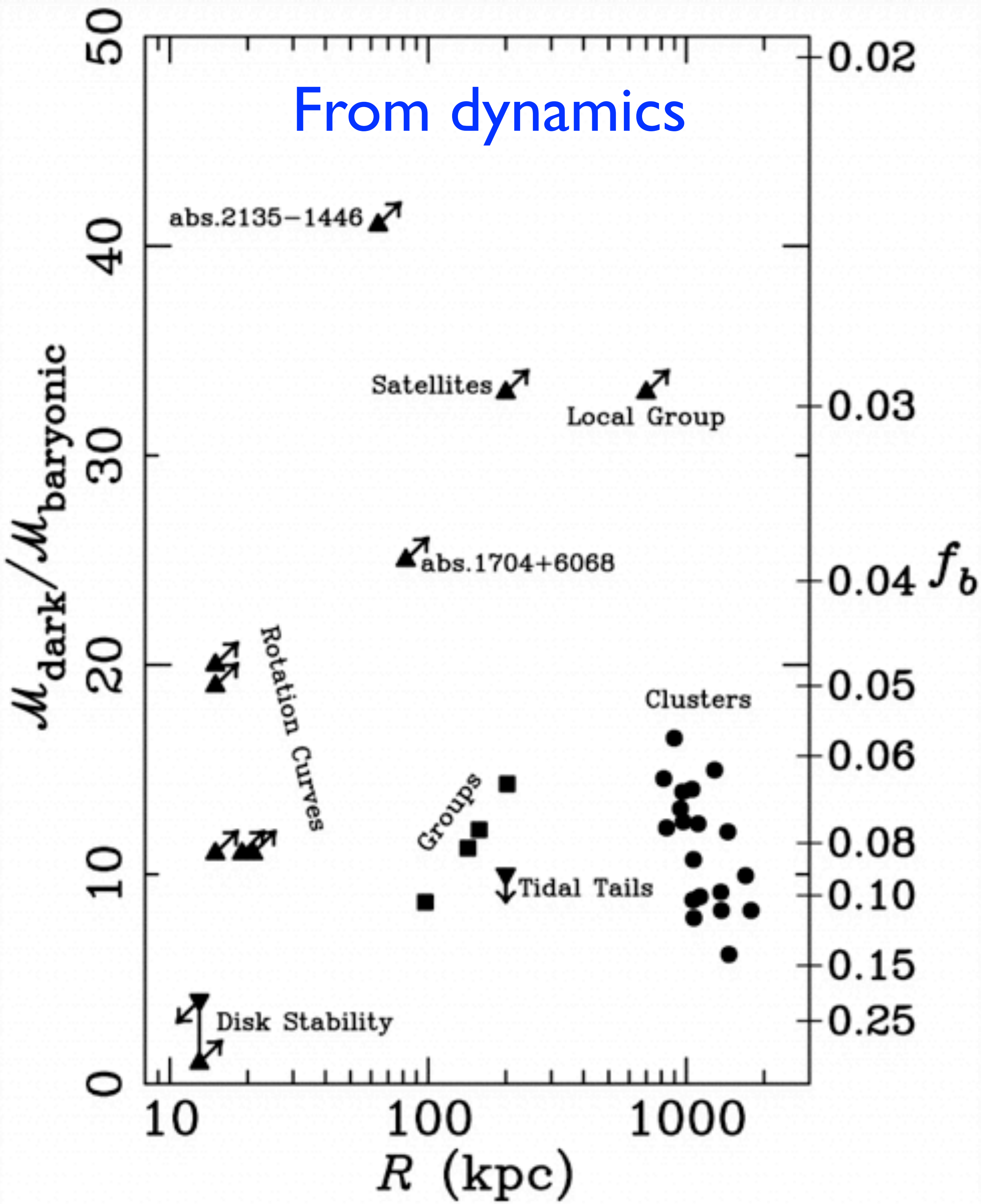
From cosmology

$$\Omega_m \approx 6\Omega_b$$

The gravitating mass density exceeds the baryon density from Big Bang Nucleosynthesis (BBN)

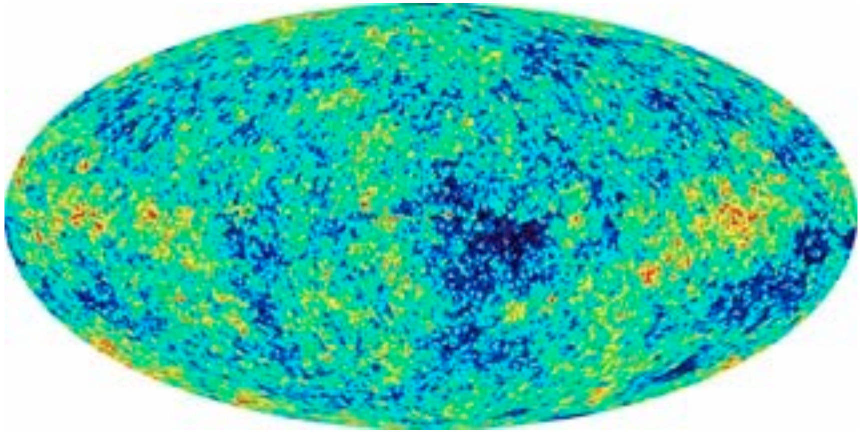
or equivalently, the baryon fraction

$$f_b = 0.17$$



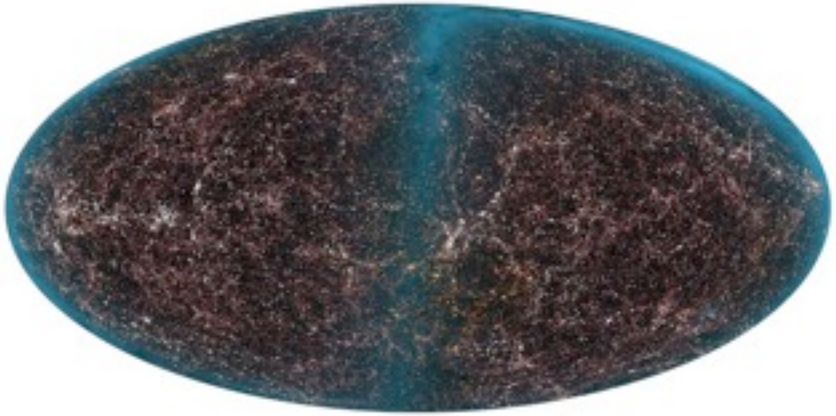
(2) There isn't enough time to form the observed cosmic structures from the smooth initial conditions unless there is a component of mass independent of photons.

t = 3.8 x 10^5 yr



very smooth: $\delta\rho/\rho \sim 10^{-5}$

t = 1.4 x 10^{10} yr



very lumpy: $\delta\rho/\rho \sim 1$

$$\delta\rho/\rho \propto t^{2/3}$$

These considerations made CDM the dominant paradgim

Only requirement to be CDM is

- dynamically cold (slow moving)
- non-baryonic (no E&M interactions)

could be
WIMPS
(or some other particle)
or
Black Holes
(masses of ~ $10^5\ M_\odot$ conceivable)

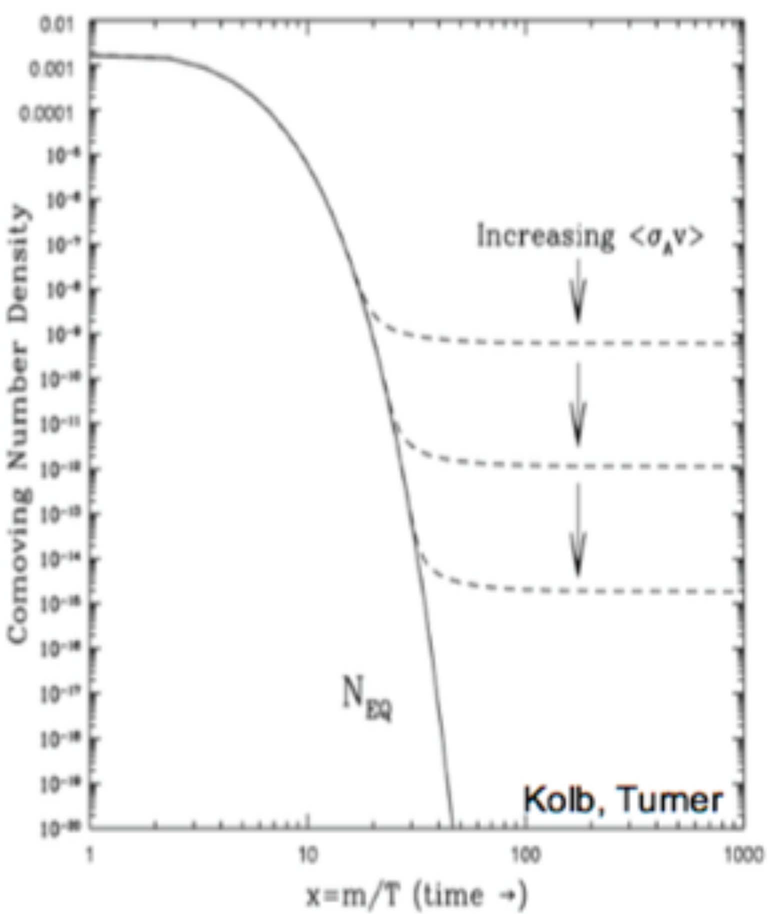
Two big motivations for CDM:

1) total mass outweighs normal mass from BBN

2) needed to grow cosmic structure

WIMPs are considered the odds-on favorite CDM candidate because of the so-called `WIMP miracle': the relic density of a new weakly interacting particle is about right to explain the mass density.

THE WIMP MIRACLE

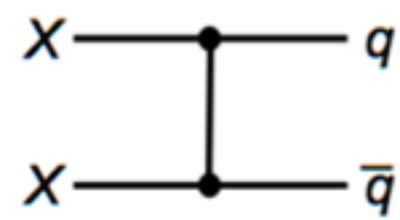


In the very early universe

- Assume a new (heavy) particle *X* is initially in thermal equilibrium

- Its relic density is

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$



- $m_X \sim 100$ GeV, $g_X \sim 0.6 \rightarrow \Omega_X \sim 0.1$

- Remarkable coincidence: particle physics independently predicts particles with the right density to be dark matter

Lots of particle candidates for CDM:

WIMPs
Axions
Light dark matter
wimpzillas (m > 1 TeV)
etc.

Can imagine other candidates as well:

Warm DM (m ~ a few KeV)

Self-interacting DM
(posits new force that only acts in the dark sector)

etc.

Motivations for non-baryonic Dark Matter:

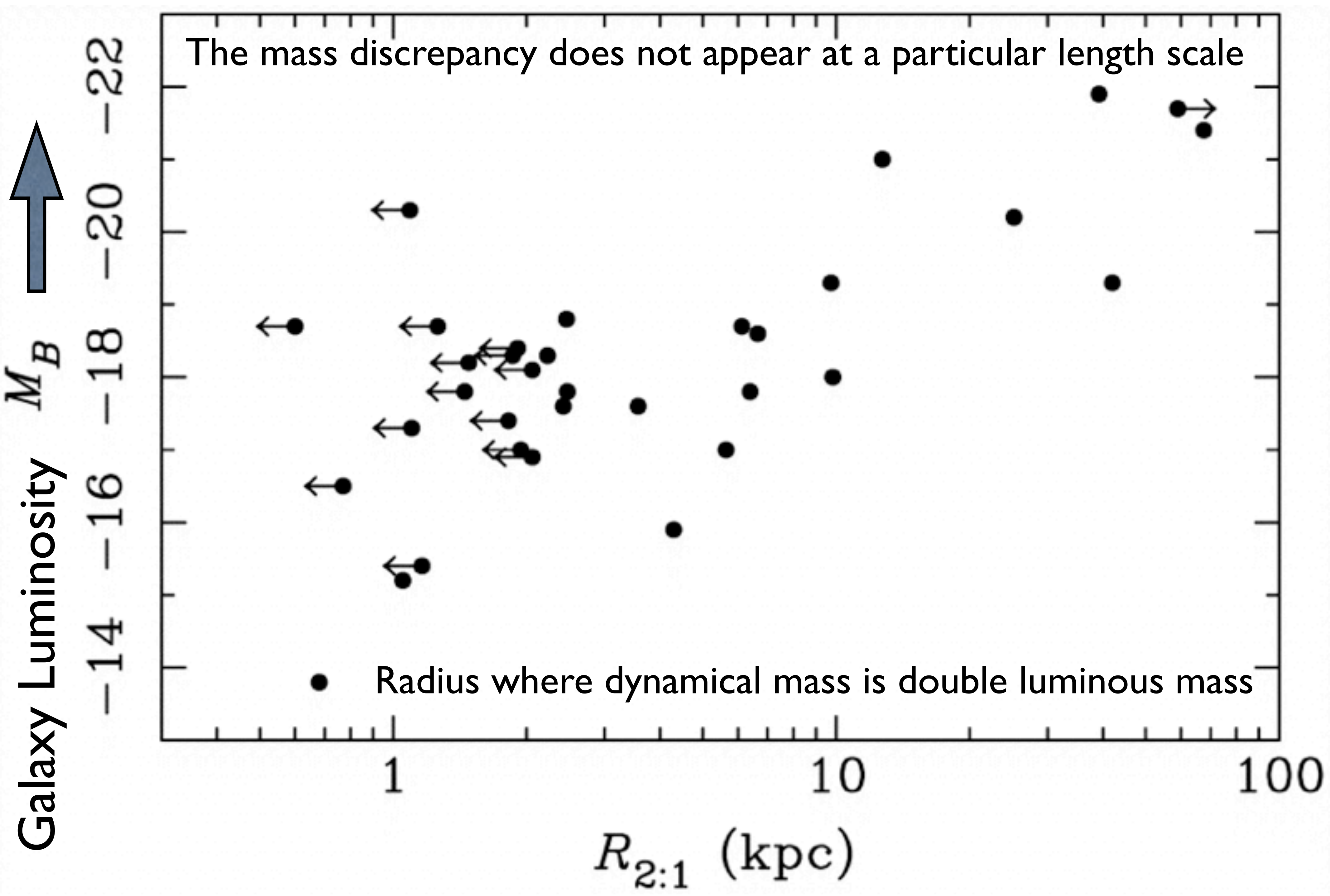
1) total mass outweighs normal mass from BBN

2) needed to grow cosmic structure

(1) and (2) hold only when gravity is normal.

Leaves room to consider modifications of dynamical laws (e.g., gravity or inertia) as alternatives to dark matter.

Can exclude length-scale based modifications



Potentially viable modified dynamical theories

MOND (Modified Newtonian Dynamics) [Milgrom]

can be interpreted as either a modification of gravity or of intertia

modification at a critical acceleration scale

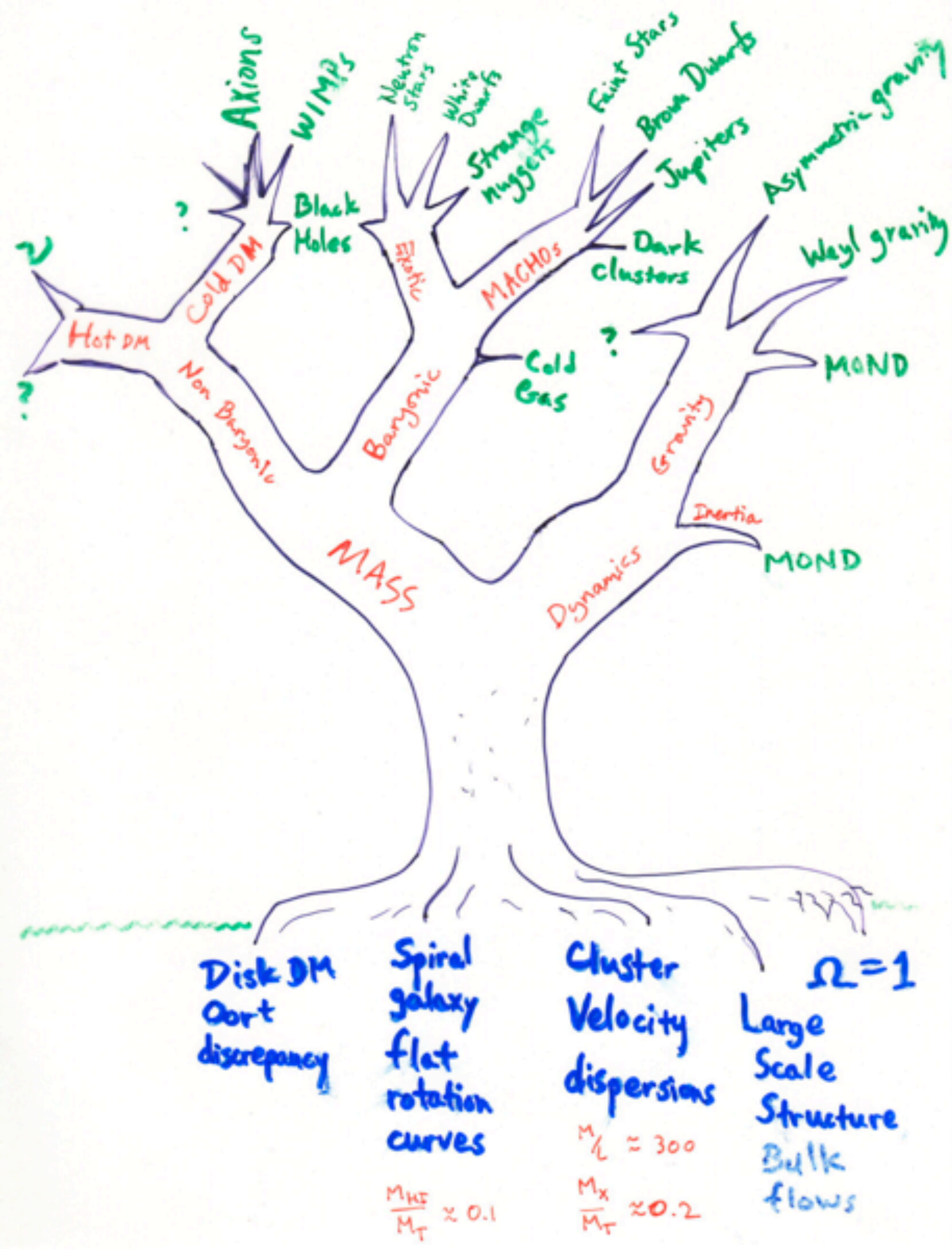
$a_0 \sim 10^{-10}$ m/s/s

Conformal Weyl Gravity [Mannheim]

4th order extension of General Relativity

Others?

Not easy to build a theory that is consistent with all known facts



Enough with the crazy ideas

Back to observations

Dark Matter has always been driven by data - specifically, astronomical observations of large structures like galaxies, clusters of galaxies, and the universe as a whole.

Coma cluster velocity dispersion

AMICS OF COMA CLUSTER 443

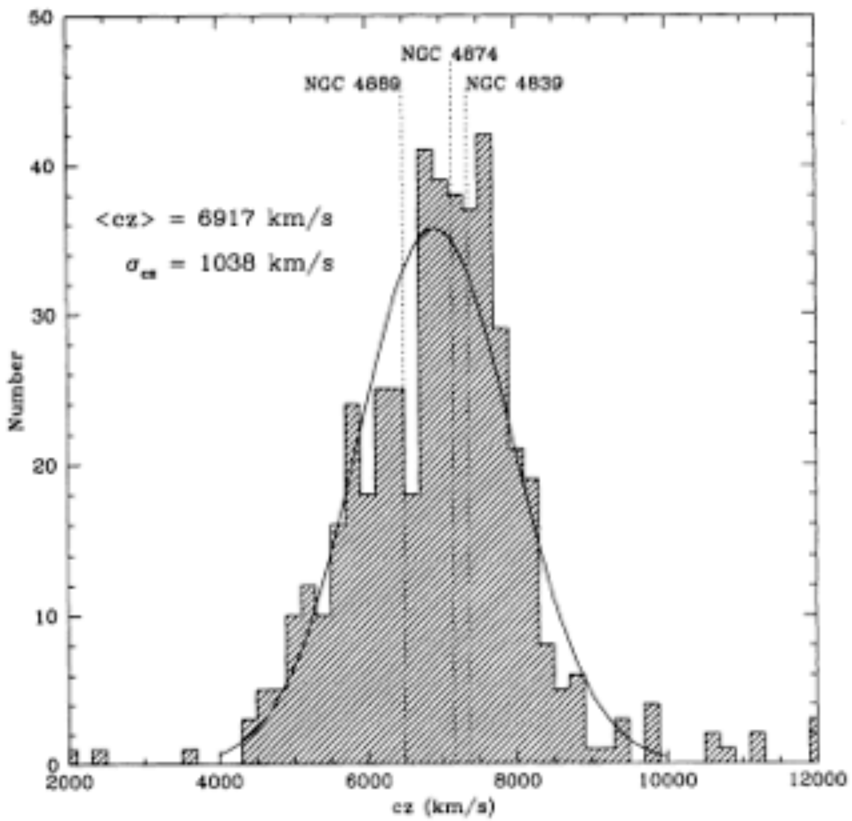


FIG. 5.—Distribution of radial velocities for galaxies in the Coma cluster. The curve is a Gaussian with mean 6917 km s^{-1} and standard deviation 1038 km s^{-1}. The velocities of the three dominant cluster galaxies are indicated.

Colless & Dunn 1996

An alternative visualization of the subclustering is provided by Figure 10, which shows the smoothed density of galaxies as a function of velocity and distance from the cluster center along the NE–SW diagonal [i.e., $(X + Y)/2^{1/2}$, with NE

NGC 4874 and NGC 4889, it is no surprise to see that these two dominant galaxies are projected in the spatial dimension onto the primary and secondary peaks, respectively, in the core galaxy distribution. Contrary to naive expectation, however,

Coma (smoothed)

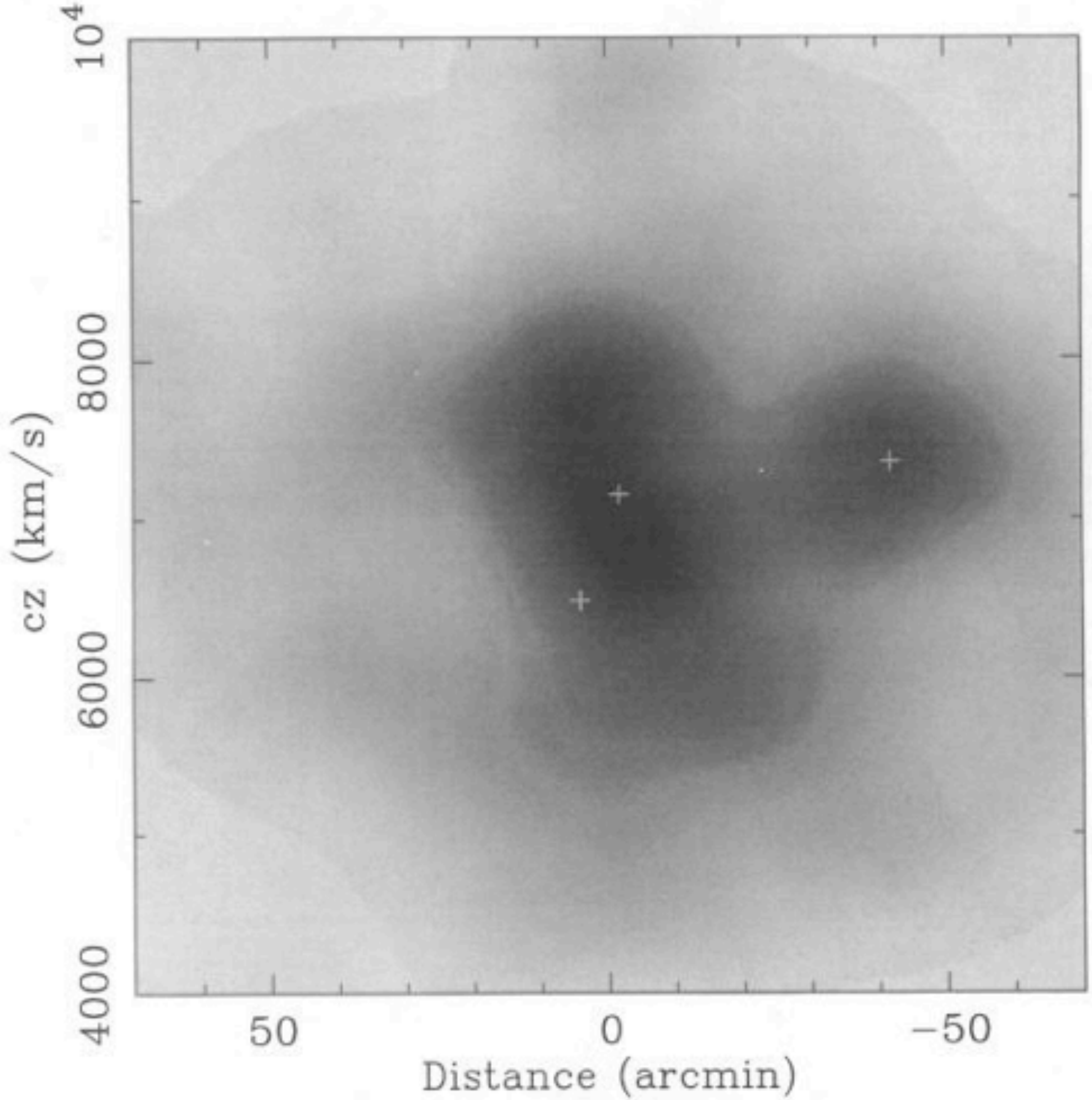


FIG. 10.—Galaxy density distribution projected onto the plane of radial velocity versus projected distance from the cluster center along the NE–SW diagonal (NE positive). The density is smoothed with a Gaussian of dispersion 8′ in the spatial dimension and 300 km s^{-1} in the velocity dimension. The positions of the three dominant galaxies are marked by crosses (*left to right*: NGC 4889, NGC 4874, NGC 4839). The gray scale is linear with density and runs from zero to the maximum.